National Semiconductor

July 1989

LM1575-5.0/LM2575-5.0 Simple Switcher Step-Down Voltage Regulator

General Description

The LM1575/LM2575 are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator. These devices feature a 5V output capable of driving a 1A load with excellent line and load regulation.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM1575/2575 offers a high efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in many cases no heat sink is required.

A standard series of inductors are available from several different manufacturers optimized for use with the LM1575/LM2575. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±3% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring less than 200 μA standby current. The output switch includes current limiting, as well as thermal shutdown for full protection under fault conditions.

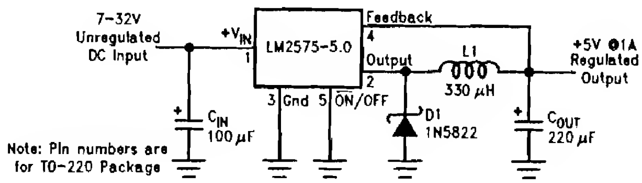
Features

- 5V output, ±3% Max over line and load conditions
- Guaranteed 1A output current
- Wide input voltage range, 7V to 35V
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- Low power standby mode, I_Q typically <200 μA
- 82% efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection

Applications

- Simple high-efficiency step-down regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators

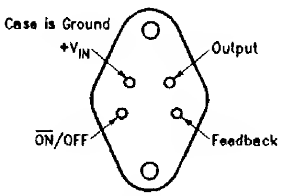
Typical Application



TL/H/10527-1

Connection Diagram and Order Information

4-Lead TO-3 (K)

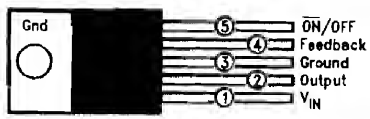


TL/H/10527-2

Bottom View

Order Number LM1575K-5.0, LM2575K-5.0
See NS Package Number K04A

5-Lead TO-220 (T)



TL/H/10527-3

Top View

Order Number LM2575T-5.0
See NS Package Number T05A

For information about LM2575 in dual-in-line or surface-mount packages, contact the factory.

RRD-B20M89/Printed in U. S. A.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage (see *Figure 5*)	40V
$\overline{\text{ON}}$/OFF Pin Input Voltage	$-1 \leq V \leq 15V$
Output Voltage to Ground (Steady State)	$-1V$
Power Dissipation	Internally Limited
Storage Temperature Range	$-65°C$ to $+150°C$
Minimum ESD Rating ($C = 100$ pF, $R = 1.5$ kΩ)	2 kV
Lead Temperature (Soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C
Operating Temperature Range	
LM1575-5.0	$-55°C \leq T_J \leq +150°C$
LM2575-5.0	$-40°C \leq T_J \leq +125°C$

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$, and $I_{LOAD} = 200$ mA.

Symbol	Parameter	Conditions	Typ	LM1575-5.0 Limit (Note 2)	LM2575-5.0 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 1*						
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$	5.0	 4.950 5.050	 4.900 5.100	V V (Min) V (Max)
V_{OUT}	Output Voltage	$0.2A \leq I_{LOAD} \leq 1A$, $8V \leq V_{IN} \leq 35V$	5.0	 4.850/**4.800** 5.150/**5.200**	 4.800/**4.750** 5.200/**5.250**	V V (Min) V (Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$, $V_{OUT} = 5V$	82			%
DEVICE PARAMETERS						
f_O	Oscillator Frequency		52	 47/**43** 58/**62**	 47/**42** 58/**63**	kHz kHz (Min) kHz (Max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 1A$ (Note 5)	0.9	 1.2/**1.4**	 1.2/**1.4**	V V (Max)
DC	Max Duty Cycle (ON)	(Note 6)	98	 93	 93	% % (Min)
I_{CL}	Current Limit	Peak Current, $t_{ON} \leq 3$ µs (Note 5)	2.2	 1.7/**1.3** 3.0/**3.2**	 1.7/**1.3** 3.0/**3.2**	A A (Min) A (Max)
I_L	Output Leakage Current	$V_{IN} = 35V$, (Note 7), Output $= 0V$ Output $= -1V$	 7.5	2 30	2 30	mA (Max) mA mA (Max)
I_Q	Quiescent Current	(Note 7)	5	 10/**12**	 10	mA mA (Max)
I_{STBY}	Standby Quiescent Current	$\overline{\text{ON}}$/OFF Pin $= 5V$ (OFF)	50	 200/**500**	 200	µA µA (Max)
θ_{JA} θ_{JC} θ_{JA} θ_{JC}	Thermal Resistance	K Package, Junction to Ambient K Package, Junction to Case T Package, Junction to Ambient T Package, Junction to Case	35 1.5 40 2			°C/W
ON/OFF CONTROL Test Circuit *Figure 1*						
V_{IH} V_{IL}	$\overline{\text{ON}}$/OFF Pin Threshold Voltage	$V_{OUT} = 5V$ $V_{OUT} = 0V$	1.4 1.2	22/**2.4** 1.0/**0.8**	2.2/**2.4** 1.0/**0.8**	V (Min) V (Max)
I_{IH}	$\overline{\text{ON}}$/OFF Pin Input Current	$\overline{\text{ON}}$/OFF Pin $= 5V$ (OFF)	12	 30	 30	µA µA (Max)
I_{IL}		$\overline{\text{ON}}$/OFF Pin $= 0V$ (ON)	0	 10	 10	µA µA (Max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specitications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All limits are used to calculate Average Outgoing Quality Level, and all are 100% production tested.

Note 3: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 4: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM1575/LM2575 is used as shown in the *Figure 1* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

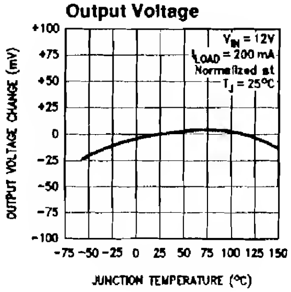
Note 5: Output (pin 2) sourcing current. No diode, inductor or capacitor connected to output.

Note 6: Feedback (pin 4) removed from output and connected to 0V.

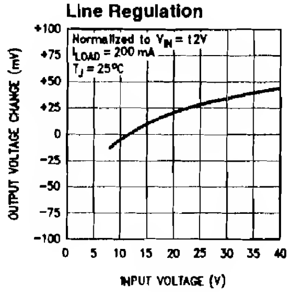
Note 7: Feedback (pin 4) removed from output and connected to 12V to force the output transistor OFF.

Typical Performance Characteristics (Circuit of *Figure 1*)

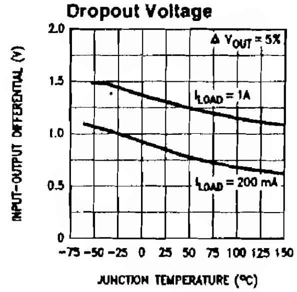
Normalized Output Voltage



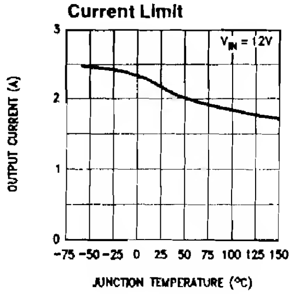
Line Regulation



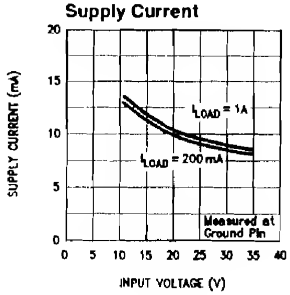
Dropout Voltage



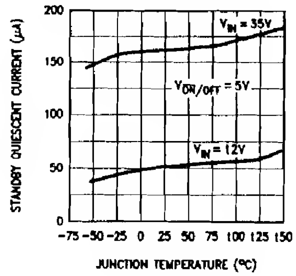
Current Limit



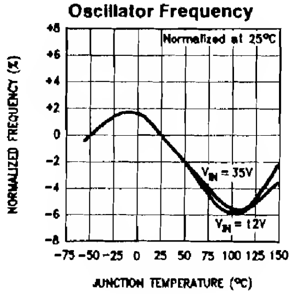
Supply Current



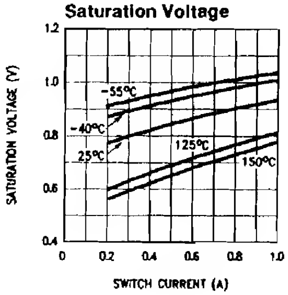
Standby Quiescent Current



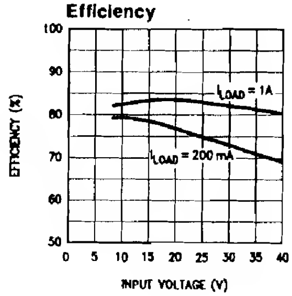
Oscillator Frequency



Switch Saturation Voltage



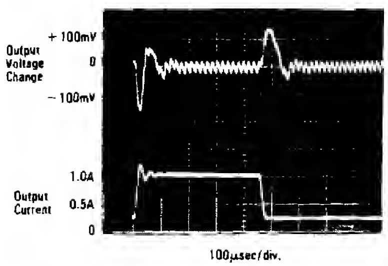
Efficiency



TL/H/10527-4

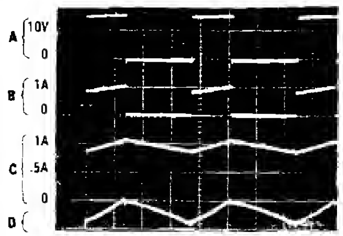
Typical Performance Characteristics (Continued)

Load Transient Response



TL/H/10527–5

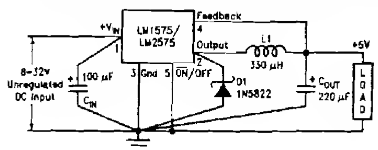
Switching Waveforms



TL/H/10527–6

A: Output pin voltage, 10V/div
B: Output pin current, 1A/div
C: Inductor current, 0.5A/div
D: Output ripple voltage, 20 mV/div, AC-coupled
Horizontal: 5 μsec/div

Test Circuit and Layout Guidelines



TL/H/10527–7

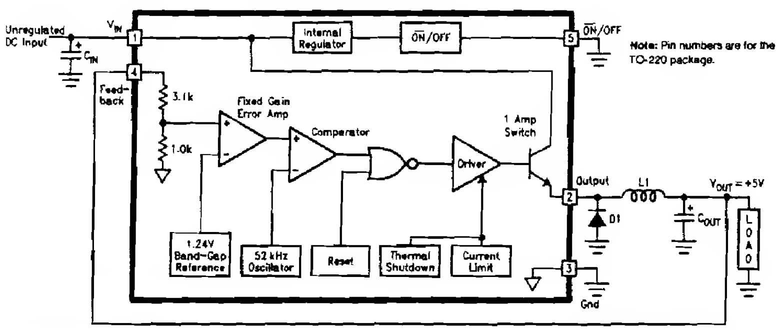
Note: Pin numbers are for the TO-220 package.

C_{IN} — 509DRSA107M050S (Sprague)
C_{OUT} — 509DRSA227M010S (Sprague)
D1 — any manufacturer
*for $V_{IN} \le 35V$, D1 should be 31DQ05 or MBR350.
L1 — 415-0926 (AIE) for $I_{LOAD} \le 0.8A$, 430-0635 (AIE) for $I_{LOAD} \le 1.0A$
5-pin TO-220 socket—2398 (Loranger Mfg. Co.)
4-pin TO-3 socket—8112-AG7 (Augat Inc.)

FIGURE 1

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which cause problems. For minimal stray inductance and ground loops, the length of the leads indicated by heavy lines should be **kept** as **short** as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results.

Block Diagram and Typical Application



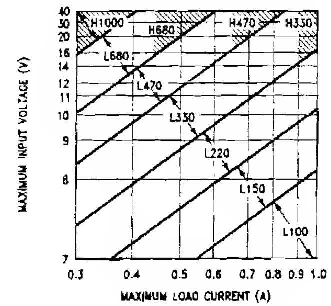
Note: Pin numbers are for the TO-220 package.

TL/H/10527–8

FIGURE 2

LM1575/LM2575 Design Procedure

Procedure	Example
Given: V_{IN} (Max) = Maximum input voltage; I_{LOAD} (Max) = Maximum load current	**Given:** V_{IN} (Max) = 18V; I_{LOAD} (Max) = 0.8A
1. **Inductor Selection (L1)**	1. **Inductor Selection (L1)**
A. From *Figure 3*, identify inductor code for region indicated by V_{IN} (Max) and I_{LOAD} (Max).	A. Code = L330
B. From *Figure 4*, identify inductor value from the inductor code.	B. Value = 330 μH
C. Select from the three manufacturer's part numbers listed in *Figure 4*. Alternately, another inductor of the appropriate value may be used. It must be rated for operation at the LM2575 switching frequency (typically 52 kHz), and for a current rating of $1.25 \times I_{LOAD}$ (Max).	C. Choose AIE 415-0926, Pulse Engineering PE 52627, or Renco RL1952



TL/H/10527–9

FIGURE 3. Inductor Value Selection Guide

Inductor Code	Inductor Value	AIE[8]	Pulse Eng.[9]	Renco[10]
L100	100 μH	415-0930	PE-92108	RL1955
L150	150 μH	415-0953	PE-53113	RL1954
L220	220 μH	415-0922	PE-52626	RL1953
L330	330 μH	415-0926	PE-52627	RL1952
L470	470 μH	415-0927	PE-53114	RL1951
L680	680 μH	415-0928	PE-52629	RL1950
H330	330 μH	430-0635	PE-53117	RL1962
H470	470 μH	430-0634	PE-53118	RL1961
H680	680 μH	415-0935	PE-53119	RL1960
H1000	1000 μH	415-0934	PE-53120	RL1959

FIGURE 4. Inductor Selection by Manufacturer's Part Number

Note 8: AIE Magnetics, Div. Vernitron Corp. Passive Components Group, (813) 347-2181
2801 72nd Street North, St. Petersburg, FL 33710

Note 9: Pulse Engineering, (619) 268-2400
P.O. Box 12235, San Diego, CA 92112

Note 10: Renco Electronics Inc., (516) 586-5566
60 Jeffryn Blvd. East, Deer Park, NY 11729

Procedure (Continued)	Example (Continued)
2. Output Capacitor Selection (C_{OUT}) A. The output capacitor value and the type of capacitor used will determine the amount of ripple voltage that appears as the output. A value of between 220 μF and 1000 μF is recommended. Selecting a low ESR (Equivalent Series Resistance) capacitor will result in the lowest amount of ripple. The lower capacitor values will allow typically 50 mV to 150 mV of output ripple, while larger-value capacitors will reduce the ripple to approximately 35 mV to 50 mV. To further reduce the output ripple voltage, several low-value standard capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency", "low-inductance", or "low-ESR". These will reduce the output ripple to 10 mV to 20 mV. However, reducing the ESR below 0.05Ω can cause instability. For this reason, the use of tantalum capacitors is not recommended. B. The capacitor's voltage rating should be at least 1.25 times greater than the output voltage. For a 5V regulator, a rating of at least 6.3V is appropriate, and a 10V rating is recommended.	**2. Output Capacitor Selection (C_{OUT})** A. C_{OUT} = 220 μF to 1000 μF standard aluminum electrolytic or C_{OUT} = 470 μF to 1000 μF high-grade capacitor (see text) B. Capacitor voltage rating = 10V
3. Catch Diode Selection (D1) The catch diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand continuous shorted output conditions, the diode current rating should be greater than 3A. The most stressful condition for this diode is an overload or short circuit condition. A. The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage. B. Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in 5V switching regulators. Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. *To prevent damage to the LM2575, fast-recovery diodes should not be used for $V_{IN} \geq 35V$.* Standard 60 Hz diodes (e.g., 1N4001, etc.) are also not suitable. See *Figure 5* for Schottky and "soft" fast-recovery diode selection guide.	**3. Catch Diode Selection (D1)** A. For this example, a 20V rating is adequate. B. Use the 1N5821 or 31DQ03 Schottky diodes, or any of the suggested fast-recovery diodes.

V_{IN} (Max)	Current Rating	Use Part Number (or Equivalent)	
		Schottky	Fast-Recovery
20V	3A	1N5821 31DQ03	FR302, HER302 or MR850 (All These are Rated over 35V)
30V	3A	1N5822 or 31DQ04	
40V	3A	31DQ05 MBR350	*Not Recommended (See Text)*

FIGURE 5. Diode Selection Guide

Application Hints

Input Capacitor (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 22 μF electrolytic capacitor. The capacitor's leads must be kept short, and located as close as possible to the regulator.

If the operating temperature range includes temperatures below −25°C, the input capacitor value may need to be larger. (This also applies to the output capacitor.) With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than 1.2 × $(t_{ON}/T) \times I_{LOAD}$.

Feedback Connection

The LM2575 feedback circuitry is designed so that, when the output voltage is connected directly to the Feedback pin, the output voltage is 5V.

$\overline{ON}$/OFF Input

For normal operation, the $\overline{ON}$/OFF pin should be grounded or driven with a low-level TTL voltage. To put the regulator into standby mode, drive this pin with a high-level TTL signal.

Application Hints (Continued)

Grounding

To maintain output voltage stability, the power ground connections must be low-impedance (see *Figure 1*). For the TO-3 style package, the case is ground. For the 5-lead TO-220 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper leadframe.

Heat Sink/Thermal Considerations

In many cases, no heat sink is required to keep the LM2575 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (150°C for LM1575 or 125°C for the LM2575). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum temperatures should be selected.
4. LM2575 package thermal resistances θ_{JA} and θ_{JC}.

Total power dissipated by the LM2575 can be calculated as follows:

$$P_D = (V_{IN})(I_S) + (V_O/V_{IN})(I_{LOAD})(V_{SAT})$$

where I_S (supply current) and V_{SAT} can be found in the Characteristic Curves shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky is used as the catch diode.

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)(\theta_{JA})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)(\theta_{JC} + \theta \text{interface} + \theta \text{Heat sink})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

Definition of Terms

Buck Regulator

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

Catch Diode

The diode which provides a return path for the load current when the LM2575 switch is OFF.

Duty Cycle (D)

Ratio of the output switch's on-time to the oscillator period.

$$D = \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}} \text{ for buck regulator}$$

where T is the oscillator period, typically 1/52 kHz.

Efficiency (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

Equivalent Series Inductance (ESL)

The pure inductance component of a capacitor (see *Figure 6*). The amount of inductance is determined to a large extent on the capacitor's construction.

TL/H/10527-10

FIGURE 6. Simple Model of a Real Capacitor

Equivalent Series Resistance (ESR)

The purely resistive component of a real capacitor's impedance. (see *Figure 6*). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.

Most standard aluminum electrolytic capacitors in the 220 μF–1000 μF range have 0.1Ω to 0.3Ω ESR. Higher-grade capacitors ("low-ESR", "high-frequency", or "low-inductance") in the 220 μF–1000 μF range generally have ESR of less than 0.15Ω.

Output Ripple Voltage

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current. The peak-to-peak value of this sawtooth ripple current will be typically 40% of the maximum load current (when the Design Procedure in the datasheet is followed).

Ripple Current

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

Standby Current (I_{STBY})

Supply current required by the LM2575 when in the standby mode ($\overline{ON}$/OFF pin is driven to TTL-high voltage), thus turning the output switch OFF.

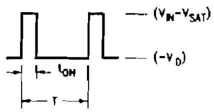
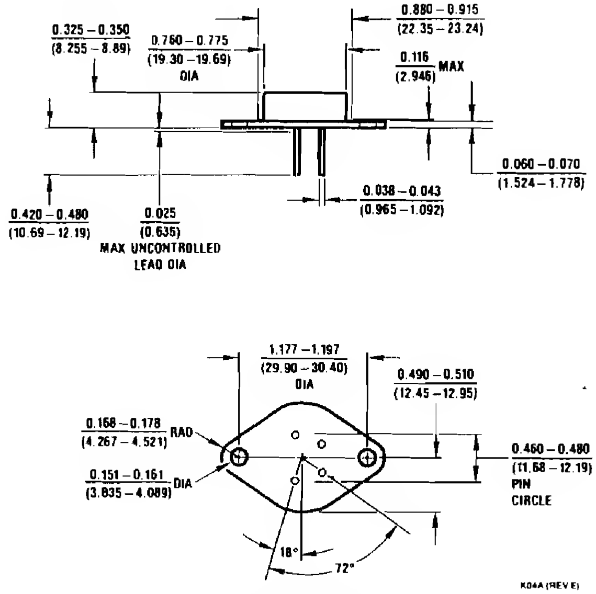
Pin Name	Pin Number (TO-220 Pkg.)	Normal Operation: Voltage Waveform & Values	Observed Problem: Condition	Observed Problem: Probable Reason	Observed Problem: Solution
Feedback	4	DC, V_{OUT} (5V Typ.) Plus Tri-Wave Ripple Voltage Plus Switching Noise	$0 < V4 < 5V$	V_{IN} Is Too Low Regulator Is in Current Limit	Increase V_{IN} to 7V Reduce Load to Less Than 1A
			$V4 = 0V$	ON/OFF Pin Is Not "Low"	Apply Correct Voltage to ON/OFF Pin
Output	2	Pulse Train  $T = 1/f_{OSC} \approx 19.2\ \mu s$ (Typ.) $\frac{t_{ON}}{T} \approx \frac{V_{OUT}}{V_{IN}}$	No Pulse Train Observed but $V_{OUT} = 5V$	Regulator Is Unloaded	Add 200 mA Load to Observe Switching
			Pulse Width Not Steady or Stable	Scope Not Triggered	Adjust Scope Trigger
				C_{IN} Is Too Far from LM2575	Reposition Capacitor as Close as Possible to Input Pin, so That Lead Length $\leq 1''$
				Regulator Is in Current Limit	Reduce Load to Less Than 1A
				"Hard" Fast Recovery Diode Used	Change Diode to Schottky or "Soft" Fast Recovery Type (as Recommended)
				LM2575 Not Seated Firmly in Its Socket (if Used)	Improve Connections of Device to Circuit
ON/OFF	5	DC, 0V	$V5 > 0V$	Pin Control Not Set for Normal Operation (Improper Logic or Connection)	Apply Correct Voltage to Pin
Ground (Case of TO-3 Pkg.)	3 (Tab)	DC, 0V	Noisy	Probe Ground Lead Is Picking up Switching Noise	Use Short Ground Lead ($\leq 1''$)
V_{IN}	1	DC, V_{IN} (from Unregulated Source)	$0 < V1 < V_{IN}$	Input Supply Overloaded	Verify That Input Supply Is Capable of Delivering at Least $(5V \times I_{LOAD} \times 1.3)/V_{IN}$ Amps

FIGURE 7. LM2575 Troubleshooting Guide

Physical Dimensions inches (millimeters)



4-Lead TO-3 (K)
Order Number LM1575K-5.0, LM2575K-5.0
NS Package Number K04A